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QoS and energy aware routing for real-time traffic in wireless sensor networks

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Abstract

Wireless sensor networks are being built to facilitate automated information gathering in military, industrial, environmental and surveillance applications. Many such applications of Sensor Networks require improved QoS (packet delivery within a defined deadline) guarantees as well as high reliability. These applications demand high packet delivery ratio and are extremely delay-sensitive. However, certain factors limit the ability of the multihop sensor network to achieve the desired goals. These factors include the delay caused by network congestion, hot regions in the network, limited energy of the sensor nodes, packet loss due to collisions and link failure. In this paper, we propose an energy aware dual-path routing scheme for real-time traffic, which balances node energy utilization to increase the network lifetime, takes network congestion into account to reduce the routing delay across the network and increases the reliability of the packets reaching the destination by introducing minimal data redundancy. This paper also introduces an adaptive prioritized Medium Access Layer (MAC) to provide a differentiated service model for real-time packets. Our claims are well supported by simulation results.

Keywords: Real-Time communication; QoS routing; Sensor networks

1. Introduction

The paradigm of ad hoc network dates back to the 1970s, when these networks were originally called *packet radio networks* [2]. The primary objective of developing such networks was to develop military and surveillance applications. Subsequently, the need for developing smart sensing devices, coupled with recent advances in MEMS technology, resulted in introduction of cheap, small sized sensor nodes [3] with formidable sensing capability. In the Smart Dust project at UC Berkeley [3] and Wireless Integrated Network Sensors [4] project at UCLA, researchers have tried to realize a functional network comprising of large number of sensors with wireless communication capabilities. These small, battery-operated nodes, equipped with sensing, computing and wireless communication capabilities are finding increased usage in many civil, industrial and military applications. A wireless sensor network is capable of functioning in hostile, inaccessible terrain without any infrastructure. However, one of the most important applications of the wireless sensor network is to provide unmanned surveillance of terrains where it is extremely difficult to bring up a traditional wireless infrastructure. These applications include forest fire detection, habitat monitoring, detecting radiation leakage, impurity level in sea discharge, intrusion detection for military purposes, etc. A lot of these applications are delay-sensitive and need the information to be transmitted to a central controller reliably within a certain deadline.

However, a wireless sensor network is resource constrained [1] and poses many challenges while designing an efficient routing protocol for deadline-driven traffic. Due to the limited battery power of the sensor nodes, it is extremely important that the routing be energy efficient, which aims at increasing the network lifetime. Besides limited energy, there are other factors which hinder the goal of transferring time critical information reliably across the network. The most common factor is the delay in routing. In typical routing schemes designed for ad hoc networks, like AODV [5], DSR [6] a lot of delay is caused because these schemes

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do not take advantage of the shortest path to the destination. If the sensor nodes are GPS enabled, then we can take the maximum advantage of the radio range by sending the packet to the node closest to the destination, thus, reducing the delay by limiting the number of hops. Other factors include the delay caused by congestion at a node and hot regions in a network, which can introduce significant delays in the delivery of real-time packets. Node mobility, link failure and node failure also add to the packet loss and affect the reliability of data delivery. All these factors together reduce the probability of successful packet delivery at the destination. Consequently, with an increase in the number of intermediate hops, the probability of packet loss also increases.

To overcome the restrictions imposed by aforementioned factors, we have to reduce the number of hops a packet has to take to reach the destination by utilizing the GPS information and the radio range of the node. However, simple geographic forwarding can cause congestion at specific nodes, leading to significant delays. Routing should thus, also factor node congestion at the forwarding nodes to deliver packets within a given deadline. At the same time, it is equally important that the routing protocol be energy aware. Energy aware routing tries to increase the network lifetime by uniform resource utilization and tries to route packets in a way that, energy consumption is distributed uniformly across the forwarding nodes. Besides, since the packet information is extremely critical, we also need to ensure the reliable delivery of the data to the destination. Reliability can be significantly improved by injecting minimal redundant information in the network. Data redundancy, in spite of its routing and energy overhead, can increase the probability of successful packet delivery at the destination and provide high reliability. However, the usefulness of aforementioned techniques in reducing packet delay is often limited by the delay at the MAC layer. This paper also introduces an adaptive prioritized MAC, which assigns higher priority to real-time packets and reduces the MAC delay for time critical data.

2. Related work

There has been a significant research in the area of real-time routing in wired networks [9,10]. The wired networks, unlike wireless sensor networks, are not limited by energy, node failure due to physical reasons, and lack of a centralized controller. It is therefore, easier to design and model a real-time wired network system. However, due to inherent problems of multihop wireless sensor networks, the design of a routing protocol, which is both QoS and energy aware, poses many new challenges and not much work has been done in this direction. The standard on demand routing algorithms for ad hoc networks like AODV [5], DSR [6] do not consider time deadlines, energy or congestion at the forwarding nodes while routing a packet to its destination. GPSR [7] maintains stateless information; however, it does not take into consideration, the congestion or the energy of the intermediate nodes. GEAR [8] takes into consideration the energy and the geographic location while forwarding the packet, but does not factor node congestion or does not ensure reliability of data packets. GEAR also does not prioritize the real-time packets over non-real-time packets to ensure better packet delivery (in time) for deadline-driven traffic. In [20], Zorzi and Rao suggest a geographic forwarding scheme where contention is done at the receiver's side. This scheme is not reliable because of possible packet loss in case of a collision. Also the receiver contention scheme only considers geographic proximity and does not take into account the energy and congestion at other nodes.

One of the most common ways of ensuring real-time packet delivery is to flood the network with the information. However, flooding has extremely poor forwarding efficiency and results in lot of redundant transmissions, increased energy consumption, and hence decreased network lifetime. A better approach is suggested in [11], where a set of disjoint paths is maintained from source to destination over which the data is transmitted. This scheme also results substantial energy overhead, suffers from cache pollution and does not consider the time constraint nature of the packets. Certain schemes like [12] require both GPS and GIS capability to find out the best route. The SPEED protocol [13] achieves the goal of forwarding the packets closer to the destination and takes into account, the presence of hot regions and congestion at forwarding nodes into its routing strategy. However, it does not take into account the energy of the forwarding nodes so as to balance the node energy utilization. Furthermore, the region it chooses for forwarding and the priority selection does not dynamically depend on the deadlines of the packets. SPEED also offers low reliability since it does not transmit any redundant data packets and uses a single route for data delivery. There are other strategies to choose an optimal path for real-time communication like minimal load routing [14], minimal hop routing, shortest distance path [15], etc. But these strategies do not specifically support the stateless architecture and the energy constraint of the sensor networks.

3. Proposed protocol

3.1. Protocol assumptions

The proposed routing scheme considers packet deadline, energy of the forwarding nodes and congestion at intermediate nodes to deliver real-time traffic. It also introduces data redundancy by duplicating data packets at